

Docket No.: AXI-144

**APPLICATION
FOR
UNITED STATES LETTERS PATENT**

Title: CURRENT INRUSH LIMITING CIRCUIT

Inventors: James R. Del Signore II
Steven M. Spano
Randolph Bullock

T0062140-D-324402Z2C60

CURRENT INRUSH LIMITING CIRCUIT

Field of the Invention:

5

The present invention relates to circuits for limiting hot-plug or DC-side power switched inrush current and, more particularly, to an inrush limiting circuit that comprises four subsystems that cooperate with each other to effectively eliminate large inrush currents regardless of the cycle time of the device being powered or its input capacitance.

10

15 BACKGROUND OF THE INVENTION

Circuit boards, or devices containing large power supply bulk capacitance, experience an uncontrolled initial inrush current that charges the capacitance when power is initially applied. This inrush current can cause damage to components, system disruption or permanent failure thereof.

20

Recent tests have shown that various point-of-sale

TOP SECRET//SI//FOUO//COMINT

(POS) printers have inrush current that is not properly limited. Often, attempts to resolve the problem have been primitive, and have been only marginally successful. In addition, many of these previous attempts to deal with this
5 problem have been expensive. It is not uncommon to experience disturbances or terminal resets when POS printers are connected to a POS terminal while it is powered up.

In some cases, an inrush transient may exceed thirty
10 amperes, while the peak capacity of the supply is typically twelve amperes or less. An inrush circuit for a high-speed thermal POS receipt printer must present less than ten amperes peak inrush, and be capable of providing normal operation with peak current draw of up to twelve amperes.
15

Discussion of Related Art:

Inrush current limiting has been attempted using a
20 two-step connection scheme. The two-step scheme comprises a first step applied through either a resistor or NTC thermistor device, and a second step that shunts the first device with a low impedance path. The shunting can be

20062109-A2402X260

accomplished with either field effect transistors (FETs) or silicon control rectifiers (SCRs), as illustrated in United States Patent No. 5,519,264. This method has the disadvantage of added cost of the resistor or thermistor 5 that must pass the inrush current. Such a scheme is also limited by long turn-on delays, in order to ensure safe operation of the system. This has been found necessary, due to the uncertainty of the actual charge state of the bulk capacitor over time. Such schemes are also limited to 10 situations where exact capacitor value is known.

Another common approach to the problem has been to sense the current with a resistor shunt and use a DC current feedback control to modulate the power control device, as 15 shown in United States Patent Nos. 5,572,395, 4,494,064 and 5,991,175. While this approach can work better over a greater parts variation, than do delay circuits, it requires the addition of a current sensing resistor that reduces the load regulation of the system.

20

Others have applied various ramps to the gate of a power control FET, as illustrated in United States Patent Nos. 4,631,470, 5,283,707, 5,374,887 and 5,703,769. These

T00500-82402460

approaches seek to gain some degree of control of the rate of rise of output voltage, and thus seek to control the inrush current presented to the supply.

- 5 These schemes are limited by the large variation in turn-on behavior of the FET. The output voltage is not linear with ramp voltage, nor is the current output, when the ramp is applied to the gate of the FET. These applied ramps are generally derived from an RC exponential decay.
- 10 Upon reaching the threshold, unless the gate ramp is slowed suddenly, the device switches from OFF to ON in short order. This limits any attempt to control this action. Extremely long gate time constants have been tried to remedy this situation.
- 15 One scheme that is similar to that of this invention is shown in the United States Patent No. 5,272,584. This approach uses the same linear, closed-loop control of the power device, while delivering a controlled ramp to the load. However, this circuit is limited for use with supply-side protection of hot-plugged cards, such as PCMCIA. By contrast, the present invention deals with the load side. Furthermore, the aforementioned patent uses an auxiliary

TOKUYAMA ELECTRONICS

control line to trigger the ramp onset, prior to which
nothing happens during insertion of the card. This feature
is probably necessary for ensuring full insertion of the
PC-card prior to power-up, but is totally unnecessary in the
5 present invention.

SUMMARY OF THE INVENTION

10 In accordance with the present invention, there is provided a circuit for limiting hot-plug or DC-side power switched inrush current into electronic devices having high input capacitance. The circuit applies an active feedback-controlled voltage ramp to a bulk capacitor by
15 means of a P-channel field effect transistor that is operated linearly after a controlled delay for contact bounce. Linear output voltage ramp to the load capacitor is ensured by providing active control of the gate voltage, via an operational amplifier with voltage feedback. The ramp is
20 generated by an RC network, but only the first third of the exponential is used, wherein the waveshape is quite linear and approaches that of an ideal ramp. Since a voltage ramp applied to a capacitor implies constant current, the inrush

current is controlled to the extent that the ramp is linear.

To ensure the initial state is OFF, and the final state is Full-On, gain is applied in the feedback loop, wherein the reference voltage ramp drives the FET via the op amp. This
5 feedback loop is compensated against spurious oscillation.

The circuit is operative over a large range of component tolerances. The circuit is inexpensive, compared to previous designs. It provides for improved control over the inrush period, reduced charging time, and tolerance for wide ranges of load capacity, while assuring very low ON
10 impedance for normal operation. The circuit does not false-trigger an inrush cycle with load transients. Once connected successfully, the power management is controlled by the product firmware.

15

It is an object of this invention to provide an improved inrush circuit for electronic devices having high input capacitance.

20

It is another object of the invention to provide an inrush circuit for point-of-sale printers that is inexpensive and that has low ON impedance during normal operation.

100-210-8241022460

It is a further object of this invention to provide an inrush circuit for electronic devices that has reduced charging time and displays a tolerance for wide ranges of load capacity.

5

BRIEF DESCRIPTION OF THE DRAWINGS

10 A complete understanding of the present invention may
be obtained by reference to the accompanying drawings, when
considered in conjunction with the subsequent detailed
description, in which:

15 FIGURE 1 illustrates a block diagram of the circuit of
this invention; and

FIGURE 2 depicts a more detailed diagram of the circuit
of the invention.

20 **DESCRIPTION OF THE PREFERRED EMBODIMENT**

Generally speaking, the invention features an inrush circuit for electronic devices and, in particular, an inrush

TOKYO ELECTRON LTD.

circuit for point-of-sale printers. The circuit limits hot-plug or DC-side power switched inrush current into devices having high input capacitance. The circuit applies an active feedback-controlled voltage ramp to a bulk 5 capacitor by means of a P-channel field effect transistor that is operated linearly after a controlled delay for contact bounce. Linear output voltage ramp to the load capacitor is ensured by providing active control of the gate voltage, via an operational amplifier with voltage feedback. 10 The ramp is generated by an RC network, but only the first third of the exponential is used, wherein the waveshape is linear and approaches that of an ideal ramp. Since a voltage ramp applied to a capacitor implies constant current, the inrush current is controlled to the extent that 15 the ramp is linear.

Now referring to FIGURE 1, a block diagram of the inrush limiting circuit 10 of this invention is shown. The current inrush limiting circuit 10 is composed of four 20 subsystems:

- 1) A time delay 12 to eliminate false action during contact bounce.

2) A voltage ramp 14 applied to the reference input 16 of an operational amplifier circuit 18.

3) An operational amplifier circuit 18 to compare a
5 divided sample of the output voltage 20 to the ramp input
16, and to operate in a linear mode, causing the output
voltage 20 to approximate the input ramp multiplied by a
gain of two.

10 4) A power field effect transistor (P-FET) 22 to act in linear mode during capacitor charging, and then go to a low-impedance (full-ON) state, in order to convey the full power supply capacity to the load during normal operation.

15 These four subsystems work together to effectively eliminate large inrush currents, regardless of the cycle time of the powered printer or its input capacitance.

The circuit 10 cannot be triggered by current peaks
20 presented during normal operation, and does not interfere with power delivery to the load, after the power-up cycle is complete. The circuit 10 resets itself long before normal power draw would deplete the bulk capacitance, if power is

TOP SECRET//NOFORN

briefly interrupted. Therefore, the circuit 10 is ready to recover safely whenever power comes back.

The heart of the circuit 10 is the voltage ramp 14
5 applied to a linear feedback circuit, which forces the P-FET
22 to produce a matching voltage ramp upon the output bulk
capacitor of FIGURE 1, guaranteeing constant current until
the capacitor is charged. Thereafter, it saturates to a low
ON-state, which is limited only by Rds-ON of the P-FET 22.
10 Changes of output load capacitance affect only the value of
current during charging, and not the ability to limit its
operation.

Repeated operation of the circuit 10 at any repetition
15 rate has no adverse effect, since no temperature-dependent
parts are used.

There is no setting of timing between separate,
unrelated events, since there is a single current path. The
20 two processes that operate this system are sequential, with
the second enabled by the completion of the first. The time
delay is added to eliminate the possibility of undesired
operation during the action of inserting the connector into

TOP SECRET//SI//FOUO//~~NOFORN~~

the power source or printer jack. This addition is with virtually no added cost, and acts as further insurance.

Referring to FIGURE 2, the circuit 10 of FIGURE 1 is
5 shown in greater detail. The resistors R1 and R2 and capacitor C4 establish a reference against which resistor R3 and capacitor C5 charge, reaching threshold at about 50 ms. Operational amplifier 17 switches from low to high, raising voltage applied to resistor R4 and starting the ramp at
10 capacitor C6.

Capacitor C8 ensures that the field effect transistor
22 starts-up OFF. Capacitor C8 is minimized to prevent subsequent interference in the linear feedback loop. In
15 addition, resistors R5, R6 and R8 ensure that the initial voltage at positive input of op-amp 18 is a positive value, which forces the output high, until the ramp begins.

The effective output "ramp" is that of the input
20 multiplied by two, since resistors R6 and R8 form approximately a 2:1 divider. This forces the FET 22 drive to start out fully OFF, and end up fully ON, in addition to limiting the portion of the actual ramp that is used, for

improved linearity.

Capacitor C7 and resistor R8 compensate the operational amplifier 18, against oscillation in the linear region of 5 operation. The values chosen for resistors R7 and R9 insure deep saturation of the FET 22, while protecting the gate voltage rating.

Since other modifications and changes varied to fit 10 particular operating requirements and environments will be apparent to those skilled in the art, the invention is not considered limited to the example chosen for purposes of disclosure, and covers all changes and modifications which do not constitute departures from the true spirit and scope 15 of this invention.

Having thus described the invention, what is desired to be protected by Letters Patent is presented in the subsequently appended claims.

20

What is claimed is: